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Thermal stability of spin valves using amorphous CoFeB

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Abstract

The thermal stability of spin valves consisting of amorphous CoFeB layer(s) has been investigated. The structural properties were investigated by XRD and extended X-ray absorption spectroscopy for as-deposited and annealed films. The structure of CoFeB layer was confirmed amorphous and stable up to about 250°C. After annealing at 300°C, it became fcc-like. The MR ratio of NiO/CoFeB(2 nm)/Cu(2 nm)/CoFeB(6 nm) increased from 4 to about 8% after annealing at 200°C, while that of Co(2 nm)/Cu(2 nm)/CoFeB(4 nm) increased from 6 to about 10%.

Keywords: Spin valves; Thermal stability; Giant magnetoresistance

1. Introduction

Recently, many studies have been published on magnetoresistance (MR) read-out heads [1–4] and memory [5–8] using spin valves. We have shown that GMR due to spin dependent electron scattering appears in amorphous(a)-CoFeB/Cu/Co [9,10] and a-CoFeB/Cu/a-CoFeB/NiO [10] sandwiches. The maximum MR ratio was obtained for both sandwiches with very thin magnetic layers [11]. This is a great advantage for the reduction of demagnetizing field in preparing micromagnetic devices, such as, GMR heads for high density recording over 10 Gbit/in² and integrated magnetic memories.

Since spin valve films suffer a heat treatment to make the devices, the thermal stability of the spin valves is very important. Spin valves using NiFe alloy layers, however, are not so stable to heat treatments [12,13]. Since amorphous alloys are in a metastable state, thermal stability of amorphous spin valves is an important problem to be clarified.

In this paper, we describe the thermal stability of the GMR and the film structures of spin valves consisting of amorphous CoFeB layer(s).

2. Experimental

Spin valves were prepared using an rf magnetron sputtering system in a similar manner to that described in the previous paper [9]. One is Co(2 nm)/Cu(2 nm)/CoFeB(*t*_{CoFeB} nm) sandwiches and the other is NiO/CoFeB(2 nm)/Cu(2 nm)/CoFeB(*t*_{CoFeB} nm) spin valves [10]. For structural characterizations several kinds of multilayers other than spin valves were also prepared. The top surface of the multilayers was covered with an Au layer to conduct the electric current as well as to protect the multilayers from oxidation. The annealing was performed for 1 hour in a static magnetic field of 160 Oe applied in the same direction as the field during deposition. The film structure was investigated by XRD and also by extended X-ray absorption spectroscopy (EXAFS), which was carried out for Co and Cu K-edge with total-electron-yield (TEY) detection method.

3. Result and discussions

Fig. 1 and Fig. 2 show XRD patterns and Fourier transforms (FT) of Co K-edge EXAFS oscillations, respectively, for glass/SiN(10 nm)/CoFeB(10 nm)/Au(2 nm) trilayers before and after annealing. In XRD patterns, two peaks at 38° and 44° which correspond to Au fcc(111) and CoFe fcc(111), respectively, are observed. The intensity of Au fcc(111) peak increases rapidly after annealing at 300°C. The peak of CoFe fcc(111) appears first after annealing at 250°C and becomes still higher at 300°C.

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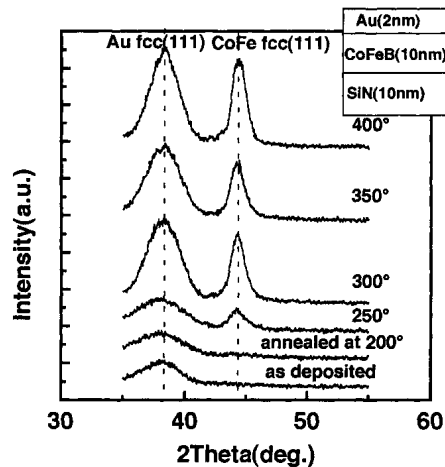


Fig. 1. XRD patterns for glass/SiN(10 nm)/CoFeB(10 nm)/Au(2 nm) trilayers after annealing at various temperatures.

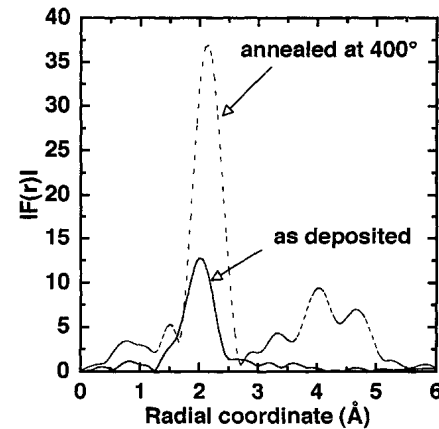


Fig. 2. Fourier transforms of Co K-edge EXAFS oscillation for glass/SiN(10 nm)/CoFeB(10 nm)/Au(2 nm) trilayers after annealing at various temperatures.

From Fourier transforms of Co K-edge EXAFS oscillations, long range ordering extending farther than second or third nearest neighbor atoms is not thought to exist, as indicated by the absence of an FT spectrum beyond the first peak. After annealing at 400°C, however, the shape of FT spectrum becomes to suggest fcc structure. The results of EXAFS as well as XRD imply that the CoFeB layer of 10 nm thick is amorphous in the as-deposited state and start crystallizing after annealing at 250°C.

Fig. 3 shows XRD patterns for (a) glass/SiN(10 nm)/CoFeB(2 nm)/Cu(2 nm)/CoFeB(2 nm)/Au(3 nm), (b) glass/SiN(10 nm)/CoFeB(6 nm)/Cu(2 nm)/CoFeB(2 nm)/Au(3 nm) and (c) glass[SiN(10 nm)/CoFeB(6

nm)/Cu(2 nm)]₂/Au(3 nm) after annealing at various temperatures. In Fig. 3a and Fig. 3b, two peaks corresponding to Au(111) and Cu(111) are observed in as-deposited samples. With rising annealing temperature, the XRD pattern includes three peaks, and finally at 400°C two peaks again, where the peak of lower angle side, at about 41°, seems to correspond to AuCu(111) and the higher angle peak, at about 44°, to CoFe(111).

The change of XRD pattern above 250°C is explained in terms of interdiffusion of Au and Cu layers. In the multilayers of (a) and (b), where the Au layer is separated from the Cu layer by an intermediate amorphous layer, the interdiffusion of Au and Cu starts after the crystallization

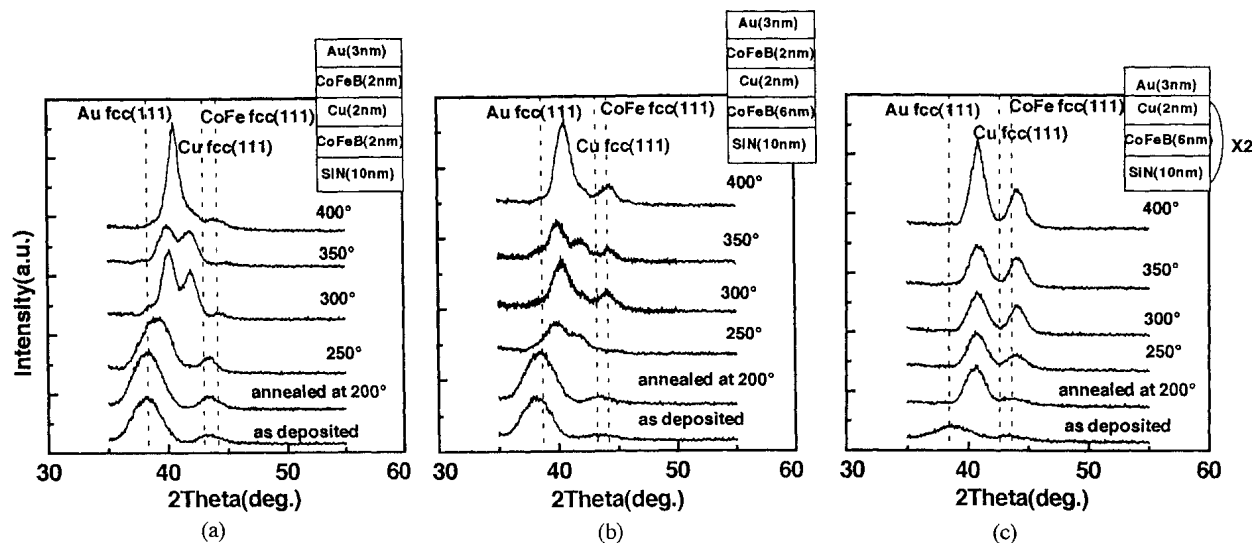


Fig. 3. XRD patterns for (a) glass/SiN(10 nm)/CoFeB(2 nm)/Cu(2 nm)/CoFeB(2 nm)/Au(3 nm), (b) glass/SiN(10 nm)/CoFeB(6 nm)/Cu(2 nm)/CoFeB(2 nm)/Au(3 nm), (c) glass[SiN(10 nm)/CoFeB(6 nm)/Cu(2 nm)]₂/Au(3 nm) after annealing at various temperatures.

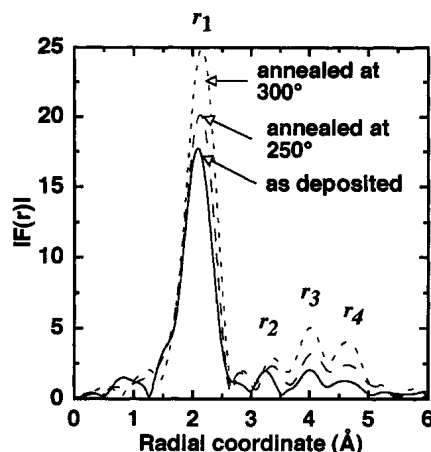


Fig. 4. Fourier transforms of Co K-edge EXAFS oscillations for a-CoFeB(2nm)/Cu(2nm)/a-CoFeB(2nm)/Au(3nm) sandwiches.

of the amorphous layer. Au and Cu atoms are thought to diffuse through the grain boundary of and/or the space between CoFe crystallites. On the other hand, in the multilayer (c), where Au and Cu layers are in contact, the interdiffusion is seen to start at a temperature lower than 200°C.

For the multilayer of Fig. 3a, Fourier transforms of Co and Cu K-edge EXAFS spectra are shown in Fig. 4 and Fig. 5, respectively. As for Co EXAFS, the peak intensity is found to increase significantly with increasing annealing temperature. In the as-deposited film, long range order peaks corresponding to the second third and fourth nearest neighbor sites (indicated with r_2 , r_3 , r_4) is very weak. After annealing at 300°C the shape of FT spectrum indicates fcc structure. On the other hand, for Cu shown in Fig. 5, the peak intensity is found to decrease significantly with increasing annealing temperature. In as-deposited films, the shape of the FT spectrum matches with the fcc

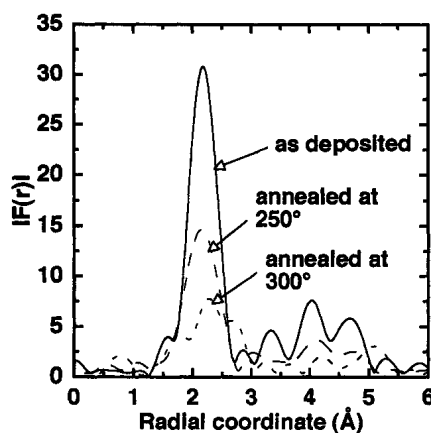


Fig. 5. Fourier transforms of Cu K-edge EXAFS oscillations for a-CoFeB(2 nm)/Cu(2 nm)/a-CoFeB(2 nm)/Au(3 nm) sandwiches.

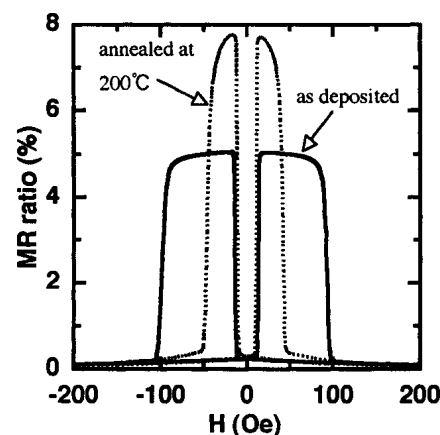


Fig. 6. MR curves for glass/SiN(10 nm)/a-CoFeB(6 nm)/Cu(2 nm)/a-CoFeB(2 nm)/NiO(10 nm) sandwiches before and after annealing at 200°C.

structure. After annealing at 300°C, however, the first peak of the spectrum shifts to a direction of a longer radial coordinate and the long range order is destroyed. This change corresponds to that of XRD in Fig. 3a and Fig. 3b, and is probably caused by the distortion of the lattice due to the coexistence of Au and Cu atoms whose atomic radii are much different from each other.

Fig. 6 shows annealing effects on the MR curves of a-CoFeB(6 nm)/Cu(2 nm)/a-CoFeB(2 nm)/NiO(10 nm) sandwiches. In Fig. 6, the MR ratio is seen to increase to about 8% after annealing at 200°C. From the MR curve, the switching field of the CoFeB layer coupled with NiO layer is seen to decrease with annealing. After annealing at 250°C, the GMR disappeared because of smaller exchange coupling. Thus the thermal stability of GMR effect itself was not clarified. For further investigation, a more stable pinning layer is necessary.

In a-CoFeB(4 nm)/Cu(2 nm)/Co(2 nm) sandwich shown in Fig. 7, the MR ratios increase to about 9 and 10% after annealing at 250 and 300°C, respectively. The

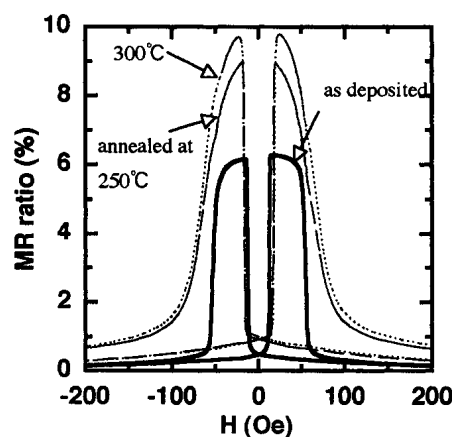


Fig. 7. MR curves for glass/SiN(10 nm)/a-CoFeB(4 nm)/Cu(2 nm)/Co(2 nm) sandwiches before and after annealing.

switching field of Co layer becomes slightly weaker after annealing, but the degradation of the pinning effect of the hard layer is not so remarkable as that of NiO, and the thermal stability as a whole is better than above spin valves. The MR ratio was enhanced on the beginning stage of crystallization. From the results of XRD and EXAFS measurements, drastic change other than the initial crystallization process can be observed. Large enhancement of MR ratios might be resulting from the structural change of the interface between Cu and magnetic layers. We need to investigate the microstructure of the interface in detail.

In conclusion, in the spin valve structure, the CoFeB layer is confirmed to be amorphous in the as-deposited state and begin to crystallize after annealing at 250°C. The GMR effect itself is not only stable up to above 300°C but also enhanced by the annealing.

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